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THRESHER AND OTHER MECHANICAL INJURY TO SEED BEANS OF THE LIMA TYPE

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THRESHER AND OTHER MECHANICAL INJURY TO SEED BEANS OF THE LIMA TYPE[1]

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INTRODUCTION

California produces annually several million pounds of both large and small lima bean seed. Much of this seed goes to eastern states, where it is used to produce either a market garden crop, in the case of the Fordhook variety, or both a market garden and a canning crop, in the case of the Henderson Bush variety.

During recent years much difficulty has been experienced, particularly in the East, in securing good stands of lima beans because of poor germination of the seed. Investigations[4, 5, 6] have shown that the cause is mechanical injury during threshing or handling. Growers and seedsmen, aware of this fact, have asked that the problem be attacked experimentally.

The following report is based primarily on results with the Fordhook and several small lima varieties. Although other types, such as certain snap beans and commercial dry shell beans, are subject to injury, limas appear to be most difficult to thresh without damaging the seed. If satisfactory methods of threshing them can be devised, the other beans can probably be handled similarly.

DESCRIPTION OF THRESHER INJURY

Growers have long recognized that some damage exists in almost all lots of machine-threshed beans. Generally, however, they have not understood that besides the visible damage there may be an even larger percentage of internal damage that cannot be detected until germination. The visible injury is in the form of split beans and cracked seed coats. This, though affecting several per cent of the crop under some

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4 Whitney, W. A. Mutilated seed—a contributing factor in defective stands of lima beans. (Abstract) Phytopathology 20(1):134–135. 1930.

5 Harter, L. L. Thresher injury a cause of baldhead in beans. Jour. Agr. Research 40:371–384. illus. 1930.

6 Borthwick, H. A. Thresher injury in baby lima beans. Jour. Agr. Research 44:503–510. illus. 1932.

threshing conditions, is less serious, from the seedsman's viewpoint, than the internal damage, because the obviously injured seeds can be recognized and removed when the beans are sorted at the warehouse.

The more serious type of thresher damage is that in which only the internal seed structure is broken. As seeds thus injured appear per-

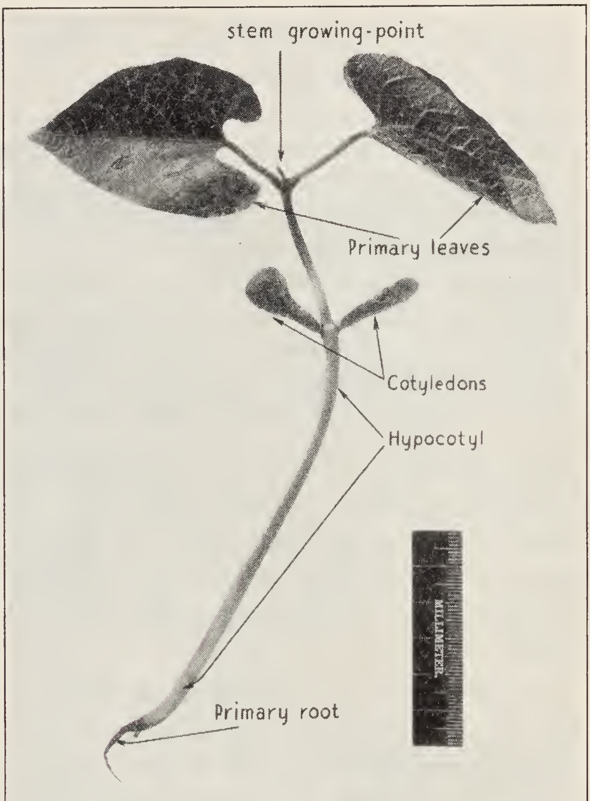

Fig. 1.—Lima bean seedling—uninjured.

fectly normal, the evidence is not found until germination. Thus, the defective seeds cannot be picked out even when known to be present in fairly large percentages.

A bean seed consists of a small dormant bean plant surrounded by a very thin seed coat. During germination this dormant plant resumes growth, bursts the seed coat, and develops into a bean seedling consisting of the primary root, the hypocotyl, two cotyledons, the stem growing-point, and the first true leaves (fig. 1). Since all of these structures are present in the bean seed before it germinates, it is obvious that they may be damaged during threshing or cleaning processes.

Fig. 2.—Various types of injuries in bean seedlings of the lima type. *A,* Baldhead; *B,* snake-head; *C,* baldhead seedling several weeks old; *D,* primary root missing; *E,* break close to cotyledons, causing them to remain below the ground.

Beans having internal injuries produce seedlings in which certain parts are either missing or defective. Often a seed may be so shattered internally that it fails to germinate at all. When planted in soil, such seeds rot without producing a seedling. If they are germinated on moist cloth or paper toweling, however, it is manifest as soon as they swell

that they have been internally shattered. One should remember that such seeds are indistinguishable from uninjured ones before they are placed on the germinator.

Other kinds of injury are numerous. Two widely recognized are the so-called baldhead and snake-head types. In the former the stem growing point and the first true leaves are missing; in the latter the two cotyledons have been detached (figs. 2 *A* and *B*). Such seedlings seldom produce a crop of any importance. The growth made by a baldhead specimen after several weeks in the greenhouse is shown in figure 2 *C*.

In still another kind of injury, the root and sometimes the lower part of the stem have been lost (fig. 2 *D*). In these cases development is greatly delayed because adventitious roots must be produced before the seedling can come up. Often the break is so close beneath the cotyledons that insufficient stem remains to raise them above ground in the manner characteristic of beans (fig. 2 *E*). The cotyledons then remain below ground, and the plumule alone elongates.

Not uncommonly seedlings have large scars on their stems or roots, indicating that certain injuries have healed during germination. Although these usually grow into average-sized plants, their early development is retarded; and probably, under some conditions of germination in the field, they may more readily fall victims to fungus diseases.

Besides the injuries described, seedlings with single cotyledons are commonly found. Sometimes scars around the point of attachment show that the cotyledons have been partly broken loose but have healed during germination. In such cases the store of reserve food is not given up to the developing seedling so rapidly as by normal cotyledons; and the result is a retarded growth that may be directly charged to thresher or other mechanical damage.

EXPERIMENTAL PROCEDURE

Description of Experimental Threshing Equipment.—A cylinder and concave unit built for a commercial bean thresher was obtained. The diameter of the cylinder, measured between tips of the teeth, was 21 inches. Teeth in the concave and cylinder bars were spaced 3 $^{15}/_{16}$ inches, and the clearance between adjacent cylinder and concave teeth was $^{5}/_{8}$ inch. Teeth faced with tool steel were used throughout.

The cylinder and concave units were mounted in a special wood frame (fig. 3) so constructed that the beans were discharged from the cylinder directly into a removable box (fig. 4), in which a false bottom made of screen was placed about 2 inches above the floor so that the threshed beans could be easily separated from the straw and unthreshed pods. This separation was made with a fork or by hand rather than with a

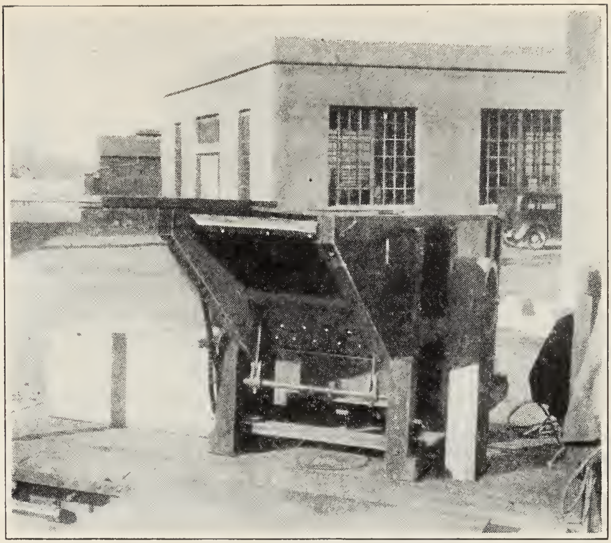

Fig. 3.—Experimental thresher.

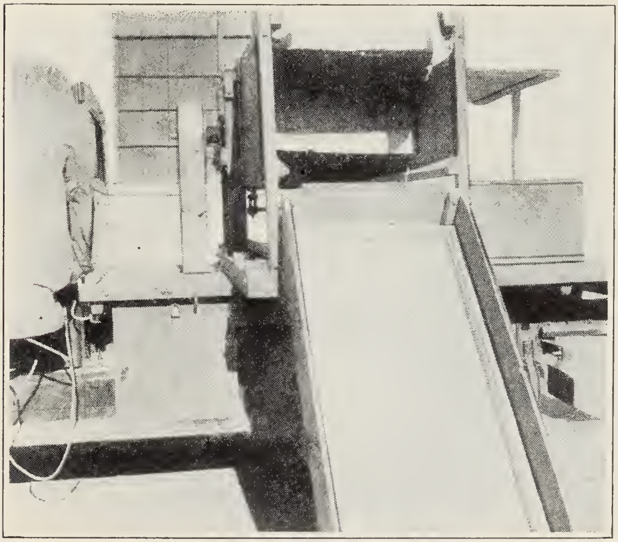

Fig. 4.—Removable container with false bottom.

special shaker, to avoid possible injury to the beans by parts of the machine other than the cylinder. A feeding table about 4 feet square was so constructed that it could be easily attached to the side of the machine. Provision was made for easy removal of the concave bars and for changing the position of the concave unit. End play of the cylinder was prevented by using set collars on both sides of each cylinder-shaft bearing.

This experimental thresher was mounted on the bed of a truck and was belt-driven from a power take-off on the truck engine, the speed of which was controlled by a screw adjustment on the carburetor. With this equipment it was possible to operate over a wide range of speeds without changing pulleys and to maintain any given velocity with a high degree of precision.

Peripheral Speed, a Function of the Cylinder Diameter.—Inasmuch as two cylinders in the same threshing machine may have different

TABLE 1

The Relation between Peripheral and Rotational Speed for Cylinders of Various Diameters

Peripheral velocity of cylinder, feet per minute	Diameter of cylinder in inches (tooth tip to tooth tip)						
	18	19	20	21	22	23	24
	Cylinder speed, revolutions per minute						
700	148	140	133	127	121	116	111
800	169	161	152	145	139	133	127
900	190	181	172	163	156	149	143
1,000	211	201	191	182	174	166	160
1,100	233	221	210	200	191	183	175
1,200	254	241	229	218	208	199	191
1,300	275	261	248	236	226	216	207
1,400	296	281	267	244	243	232	223
1,500	317	301	286	273	261	249	239
1,600	338	321	305	291	278	266	255

diameters, obviously if they are rotating at the same number of revolutions per minute the tips of their teeth will be traveling at different velocities. The cylinder of the greater diameter will therefore impart a greater impact to a bean than will the smaller cylinder. Rotational speed must be converted into linear velocity at the tips of the cylinder teeth (peripheral speed) so that the speeds of cylinders of different diameters may be compared. To do this the circumference of the cylinder at the tip of the teeth must be determined in feet and multiplied by the revolutions per minute. This gives the peripheral speed in feet per minute. For a 21-inch cylinder rotating at 200 r.p.m. the calculations are as follows:

$$\text{Peripheral speed} = \frac{21}{12} \times 3.1416 \times 200 = 1{,}100 \text{ feet per minute.}$$

Table 1 has been prepared to show the relation between peripheral and rotational speed for cylinders of various diameters.

Most of the threshing tests were made at peripheral speeds of between 770 and 1,560 feet per minute. The lower speed limit was established at

a point below which a commercial machine cannot well be operated. The upper limit was determined by the visible damage produced in the beans. Whenever the product was obviously badly damaged, no further increase in speed was made.

Experimental Threshing Practice.—When the cylinder had reached the desired speed, as determined by a direct-reading speed indicator, enough beans to yield 15 to 20 pounds of threshed seed were placed on the feeder table and were fed into the cylinder as rapidly and evenly as its speed would permit. The box containing this material, which had been through the cylinder once, was removed; and the straw and the unthreshed pods were transferred to a canvas sheet. The threshed beans remaining in the box were then cleaned by a fan and weighed. A sample of 2 or 3 pounds, obtained with a Boerner sampler, was retained for further laboratory analysis. Next the straw and the unthreshed pods were run through the cylinder again at the same speed, and the beans threshed during this run were cleaned and sampled. In most cases each lot of beans was run through the cylinder three times at the same speed. Any remaining unthreshed beans were then either shelled by hand or run through again at a much higher speed. After every run, therefore, data were available as to the percentage of beans threshed out each time through the cylinder, and samples were saved for further study. Tests resembling the one described above were made at each of five different speeds, and the entire series was repeated as many as five times.

After being threshed, the samples were brought into the laboratory and divided to about 350 grams in the case of the baby lima type and to about 1,000 grams in the case of the Fordhooks. After all foreign matter had been removed by hand picking, the samples were accurately weighed. The broken beans (those with part of the seed actually missing) and the cracked beans (those with visible skin cracks) were then measured separately and removed. From the remainder, germination samples of 400 beans were selected, all visibly undamaged, having acceptable size from a seedman's viewpoint, and apparently not diseased.

Method of Conducting Germination Trials.—All germination tests were made at 80° F. The beans were germinated between wet paper towels on wire trays—a method preferred to soil tests chiefly because it permitted daily observation of the samples and more accurate investigation of the failure of certain seeds. Each sample remained in the germinator for a week or ten days.

In some samples a few seeds failed to absorb water when placed on the germinator. This condition, known as hardshell, was always eliminated by slightly scratching the seed coat, whereupon every live seed immediately absorbed water and germinated. When large enough to

display all their parts, the seedlings were removed from the germinator and divided into damaged and undamaged lots. The damaged seedlings were further subdivided into six lots, namely: (1) internally shattered, (2) two cotyledons missing, (3) plumule missing, (4) hypocotyl or radicle missing, (5) axis cracked, and (6) one cotyledon missing.

RESULTS OF THRESHER TRIALS ON BABY LIMA BEANS

Tests on Hopi Baby Lima Beans.—Threshing tests were run in a field of lima beans of the variety Hopi 155 grown on the University Farm at Davis, California. This variety is a baby lima type selected from the native limas grown by the Hopi Indian tribe in Arizona. The moisture content was 9.1 per cent—very near the lower limit of the range encountered in practice but not uncommon in lima beans grown in the central valley of California. Five different cylinder speeds between the limits of 770 and 1,560 feet per minute were used, and the tests at each speed were replicated five times. The percentages of visible and internal damage, and of the completeness of threshing, were recorded for each lot.

TABLE 2

EFFECT OF CYLINDER SPEED ON THOROUGHNESS OF THRESHING AND ON PRODUCTION OF VISIBLE AND INTERNAL DAMAGE TO BABY LIMA BEANS OF 9.1 PER CENT MOISTURE CONTENT

Cylinder speed, peripheral-feet per minute	Per cent threshed			Per cent damaged		
	Once through cylinder	Two times through cylinder	Three times through cylinder	Visible*	Internal†	Total‡
770	70.3	85.7	92.1	0.8	7.5	7.6
940	73.9	88.0	94.6	2.4	13.9	15.1
1,150	82.6	94.0	97.6	6.2	20.7	25.0
1,330	88.3	96.5	98.6	16.2	29.4	40.6
1,560	92.2	98.5	100.0	24.2	37.3	52.5

* Based on total amount of beans threshed.
† Based on beans remaining after removal of visibly injured portion.
‡ Based on total amount of beans threshed.

Visible damage to these beans occurred at even the lowest speed used. For an average of five replications it ranged from a fraction of 1 per cent at the lowest speed to nearly 25 per cent at the highest speed (fig. 5 and table 2). Internal damage at the lowest speed amounted to approximately 7 per cent of the beans that were left after the visibly injured ones had been removed, and this increased to more than 37 per cent at the highest speed. The values in table 2 given in the column showing per cent of total damage are obtained by converting the percentages of

internal damage to the same basis as those of visible damage and adding the two. It then becomes obvious that cylinder speed has a direct influence; the damage is appreciable at even the lowest speed and becomes enormous at the highest speeds. The quality of work done by the threshing machine is usually judged in part by the visible damage produced. This method, though acceptable for commercial beans, may be very unsatisfactory for seed beans because of the internal and, therefore, invisible damage produced in the seed.

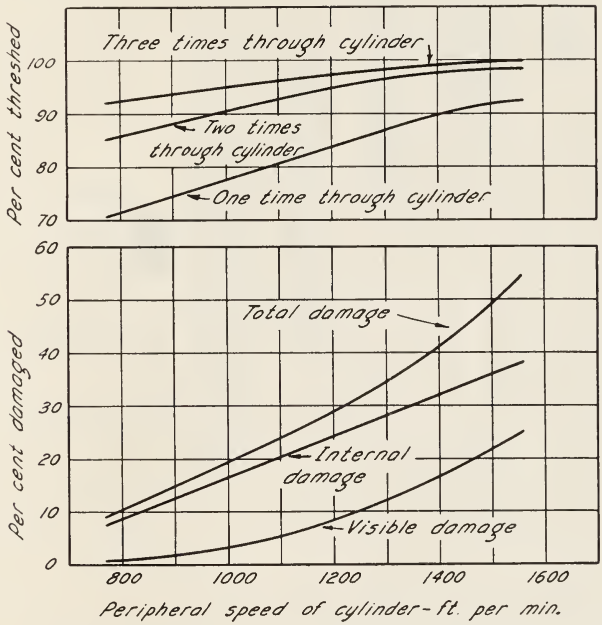

Fig. 5.—Thresher test of Hopi baby lima beans (moisture content 9.1 per cent), showing the percentage damaged as well as the percentage threshed for one, two, and three times through the cylinder at different peripheral speeds.

Thoroughness of threshing, which directly depends upon cylinder speed, is another criterion by which the quality of the work is judged. Besides threshing the seed without injury, the machine must remove all or nearly all the beans from the straw. Table 2 and figure 5 show the total percentage of the crop threshed out at the end of one, two, and three runs through the cylinder. According to these data, a machine containing three cylinders all operating at the same peripheral speed would thresh out over 90 per cent of these beans in one run through the machine at the lowest speed indicated. To do an equally thorough job with two cylinders would require a peripheral cylinder speed of nearly 1,150 feet per minute; and a single-cylinder machine would have

to operate at 1,560 feet per minute to equal the effectiveness of three cylinders running at 770 feet. These three machines operating at the speeds mentioned above would have done about 7.6, 25.0, and 52.5 per cent damage respectively (table 2). Apparently, therefore, a three-

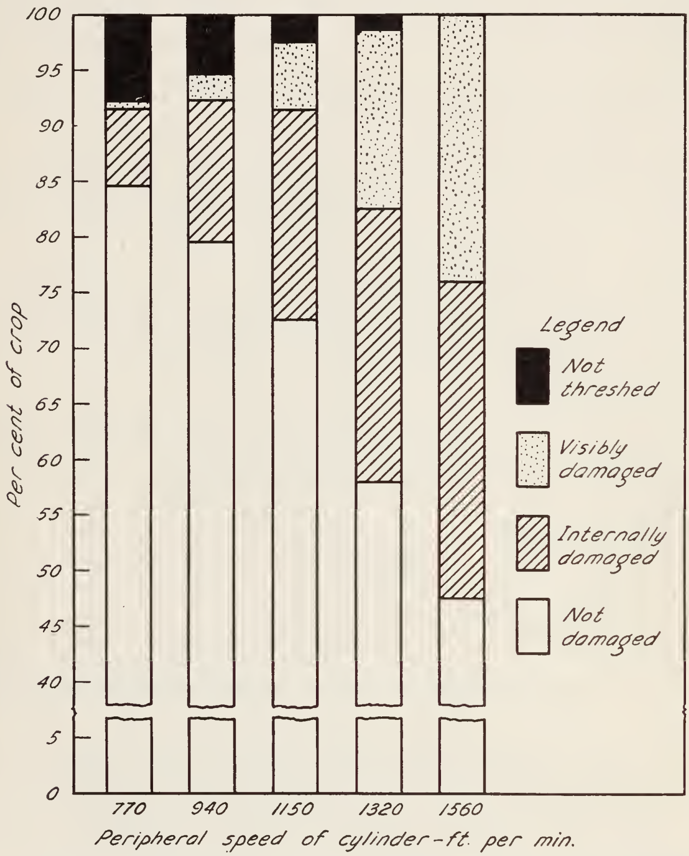

Fig. 6.—An analysis of data obtained from Hopi lima beans (moisture content 9.1 per cent), threshed at five different cylinder speeds.

cylinder machine is superior to one of fewer cylinders for threshing seed beans with minimum damage.

The question has been raised as to which of the cylinders in a machine produces the greatest percentage of damage to the beans it threshes provided they are all running at the same peripheral speed. According to threshing tests with both baby and Fordhook lima beans, there is no significant difference.

Loss Caused by Damage Compared with Loss Resulting from Incomplete Threshing.—In the preceding paragraphs the effects of cylinder

speed on visible injury, internal injury, and percentage of beans threshed have been considered separately. Although a greater percentage is threshed as the speed increases, a greater amount of damage is done. Whether or not the increased output compensates for the additional damage must now be determined. For this purpose the data discussed above have been summarized and are presented graphically in figure 6.

These data (fig. 6) may be considered from several points of view. Obviously, for example, the commercial thresherman is interested in operating his machine as fast as possible without too much visible damage, because at higher speeds he threshes out a higher percentage of the beans and finishes the work much faster.

The grower is usually paid for the seed remaining after all visibly defective beans have been removed by hand-pickers. He is therefore interested in cylinder speeds of 1,150 feet per minute or less because his output of salable beans decreases very abruptly at speeds above this point (fig. 6). Between 770 and 1,150 feet per minute he nets about the same quantity of salable beans. The grower will observe that at a speed of 1,150 feet per minute he has to pay threshing charges on 97 per cent of his crop and sells 91; the 6 per cent remaining are visibly damaged and have little commercial value. At the lowest speed, on the other hand, he sells almost all the beans threshed, has no additional threshing and hauling costs to pay, and has practically no defective beans for sale. His attempts, therefore, to secure a more complete job of threshing by speeding up the machine have not resulted in the production of more salable seed.

The seedsman would very much prefer that the beans be threshed at the slowest speed for at least two reasons. First, he has practically no cost of hand-picking because only a fraction of 1 per cent damage occurs at this speed. Second, the beans threshed at the lowest speed contain the smallest percentage of internal damage. From this point of view, the thresherman should receive a bonus, equal to the difference in cost of hand-picking, if he would run slowly.

The man who uses the beans as seed is, of course, concerned only with the internal damage; all visibly damaged beans have presumably been removed before he gets them. He therefore insists that the product contain the maximum possible percentage of undamaged seed. The beans threshed at the lowest speed most nearly meet this requirement.

According to the data obtained from the threshing tests described above, a peg-tooth cylinder does not thresh baby lima beans satisfactorily for seed purposes at any speed if their moisture content is very low. Further data concerning the influence of moisture on threshing

injury will be presented elsewhere in this bulletin. Under the conditions of the experiment, 7.6 per cent total damage occurred at a cylinder speed of 770 feet per minute. Although this is more damage than should be tolerated, the cylinder speed is too slow for practical operation of a machine.

Tests on Wilbur Lima Beans.—A second series of threshing tests was run later in the season in a field of baby limas of the Wilbur variety. These beans are a long-vined type and contained about 16.4 per cent of

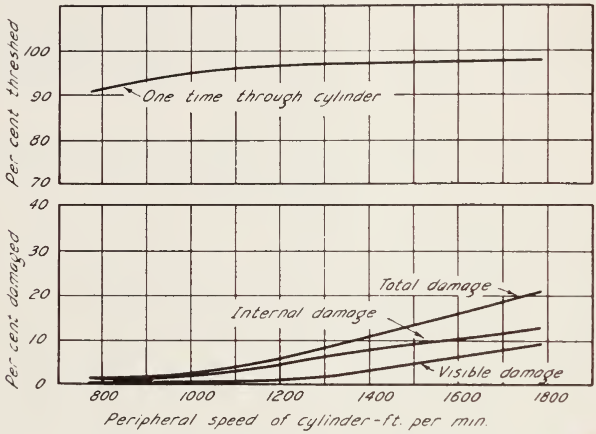

Fig. 7.—Threshing tests of Wilbur baby lima beans (moisture content 16.4 per cent), showing the relation of the amount of damage and the percentage threshed to various cylinder speeds.

moisture. Whereas the pods were dry and opened easily, the vines were green and tough, and tended to wrap around the cylinder at the lower speeds. Some of the beans, accordingly, though fed into the machine only once, may actually have gone through the cylinder several times.

The total damage varied from 1.0 to 21.0 per cent for cylinder speeds of 770 and 1,785 feet per minute, respectively, (figs. 7 and 8). From the results of these tests, two points are at once apparent. First, the injury was much less than with the Hopis discussed above, probably because of the moisture content, which was about as high as is commonly found in baby lima beans threshed for seed. Second, although the total injury was low, the effect of increasing speed was very similar to that found in the Hopis. Visible injury, for example, did not occur below a speed of 1,150 feet per minute; and at the highest speed (1,785 feet per minute) it amounted to only 9 per cent. Internal damage, though occurring at all speeds, increased along with the speed until it amounted to 13 per cent of the recleaned beans at the highest speed. It exceeded visible damage at all speeds, as shown in the previous tests. At even the lowest speed,

over 90 per cent of the seed was threshed when put through the machine once. Increasing the speed, therefore, did not greatly increase the percentage threshed.

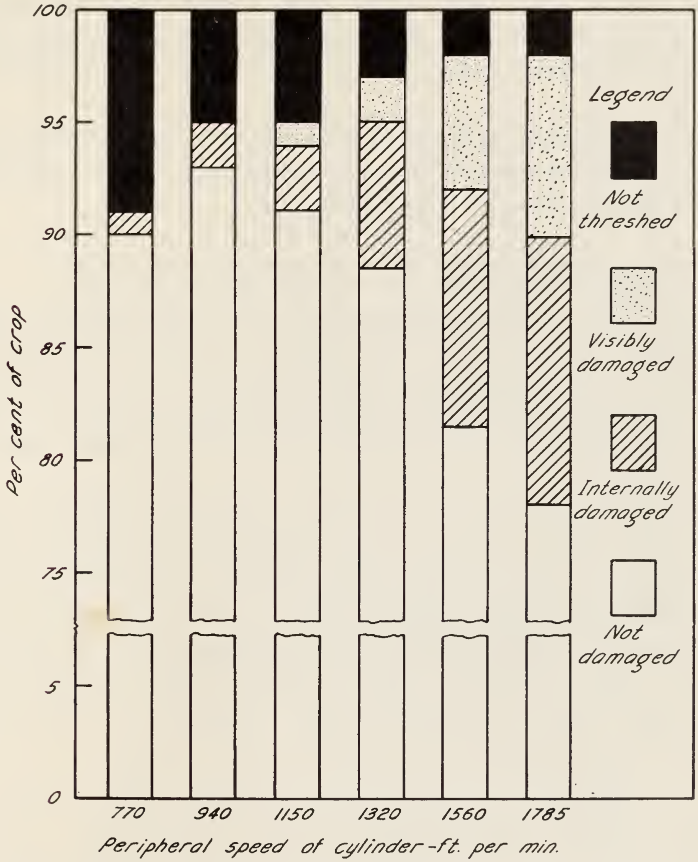

Fig. 8.—An analysis of data obtained from Wilbur baby lima beans (moisture content 16.4 per cent), threshed at six different cylinder speeds.

According to these tests (fig. 8), a speed of 770 feet per minute is too slow. At 940 feet per minute, a higher percentage of the crop can be threshed without visible damage or material increase of internal damage. The differences in internal damage at 770 and 940 feet per minute are probably not significant. In the speed range of 940 to 1,320 there is little difference in the percentage of salable beans produced; but there is a difference in the amounts of visible and internal injury—a fact indicating the desirability of maintaining the speed at the lower limit of this range. At higher speeds the per cent of salable beans decreases, and both internal and visible damage increase very rapidly.

The two series of tests described above were conducted at the extremes of moisture conditions for bean threshing. Great differences in the total damage were found in the two fields, the one with the lower moisture displaying most severe injury. In both cases the data show very clearly that high cylinder speed directly causes defective seed and that for a product of highest quality the machine should be operated as slowly as practicable.

Although a peg-tooth cylinder is unsatisfactory for threshing seed beans of low moisture content, it can be used safely when the moisture content is high, provided the speed is kept low.

THRESHING STUDIES ON FORDHOOK LIMA BEANS

The Fordhook is a large lima bean grown for seed along the coast, principally in Ventura and Santa Barbara counties. All threshing studies upon it were conducted in fields near Oxnard, Ventura County. On the morning that the work was started a light rain began to fall, which continued throughout the day and evening. In the night approximately ½ inch fell.

One three-cylinder commercial machine continued to thresh in spite of the light rain. The straw was run through the machine twice to insure the threshing of all beans. It was felt advisable to begin the thresher studies under these weather conditions and to continue as long as practicable. During this initial trial the cylinder was operated at 1,320 feet per minute (240 r.p.m.). The beans contained 16.4 per cent moisture. The vines were damp, and the pods tough. Although very little water had apparently been taken up, the beans had become somewhat soft and spongy.

The straw was run through the cylinder six times—the equivalent of two trips through a three-cylinder machine. After each run, the threshed beans were removed from the straw; those remaining after the sixth time through were shelled by hand. Approximately 75.3 per cent were threshed the first time through the cylinder. On successive runs 13.4, 5.9, 2.7, 1.4, and 0.8 per cent, respectively, were threshed. The beans not threshed amounted to 0.5 per cent. The total threshed in the first three trips through the cylinder was 94.6 per cent. Only 4.9 per cent were removed in the next three times through the cylinder. The total damage to this lot amounted to 17.4 per cent, of which 14.2 per cent was visible and 3.2 per cent was internal.

On the second day good drying weather prevailed. Although the beans were too damp for commercial threshing, the experimental work was continued. The moisture content was now 18.8 per cent.

Threshing was carried on at five cylinder speeds, ranging from 770 to

1,560 feet per minute. As shown by the data (fig. 9), the total damage was 3.5 per cent at the lowest speed, increasing to 13.5 per cent at the highest speed. The amount threshed for three times through the cylinder varied from 66.5 to 96.5 per cent.

The threshing trials were continued on the third day. Weather conditions continued favorable. The bean straw had dried sufficiently for the

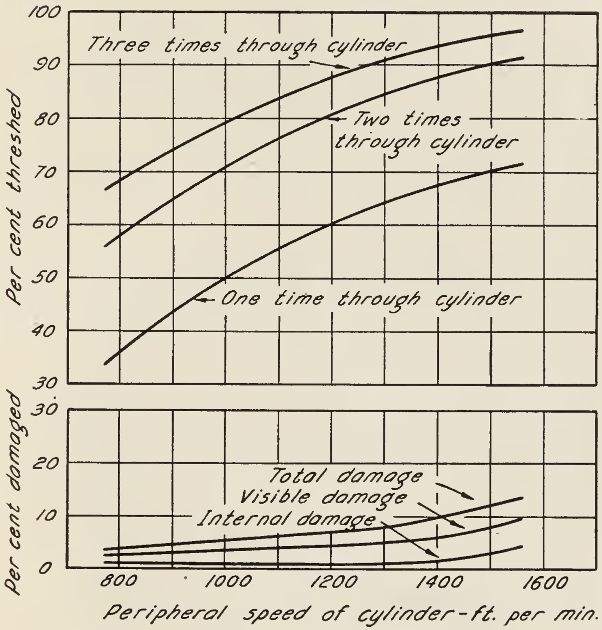

Fig. 9.—Threshing tests in Fordhook beans (moisture content 18.8 per cent). Total damage varied from 3.5 to 13.5 per cent for the different cylinder speeds. The percentage threshed for three times through the cylinder varied from 66.5 to 96.5 for the same range in speeds.

commercial machines to start, and the moisture content had dropped to 17.3 per cent. Beans were threshed at four cylinder speeds, varying from 770 to 1,320 feet per minute. As visible injury was quite evident at the latter speed, a higher one was not used.

The per cent of thresh, for three times through the cylinder, varied from 82.5 per cent at 770 feet per minute to 99.0 per cent at 1,320 feet. The total damage amounted to 2.0 per cent and 15.0 per cent, respectively, for the two speeds (fig. 10).

By the fourth day the moisture content in the beans had dropped to 15.9 per cent. The speeds used varied from 850 to 1,150 feet per minute. Threshing was discontinued with a top speed of 1,150 feet because of

the large amount of visible damage appearing. Higher speeds would have damaged the beans without adding much value to the data.

For a cylinder speed of 850 feet per minute the total damage was 3.0 per cent, and the amount threshed for three times through the cylinder was 91.5 per cent; while at 1,150 feet per minute (fig. 11) the damage was 15.0 per cent and the thresh 97.5 per cent.

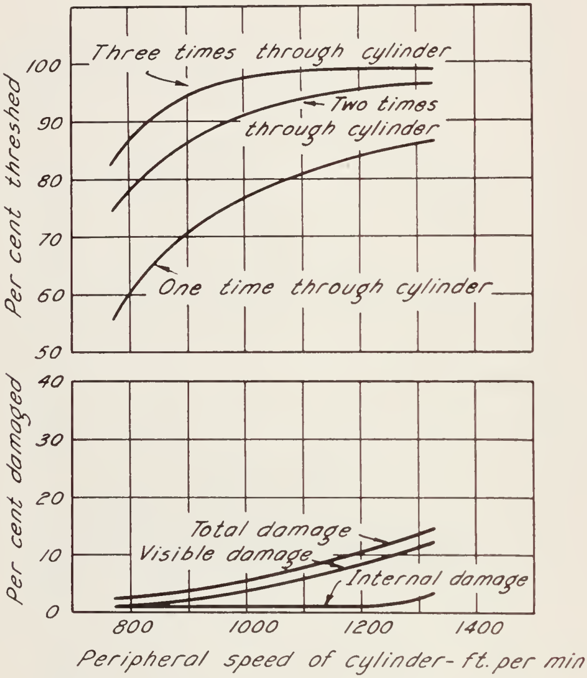

Fig. 10.—Threshing tests of Fordhook beans (moisture content 17.3 per cent). Damage varied from 2.0 to 15.0 per cent for cylinder speeds ranging from 770 to 1,320 feet per minute. The percentage threshed for three times through the cylinder varied from 82.5 to 99.0 for the same range in speeds.

Apparently the moisture content of the beans directly influences their susceptibility to damage: the higher it is, the less the damage, provided the threshing is done at a constant speed. The relation between the speeds required to produce a given amount of damage to beans of different moisture contents is shown in figure 12. For example, a total damage of 15 per cent was produced in beans containing 18.8 per cent moisture by threshing at a speed of 1,600 feet per minute; in another sample, containing 17.3 per cent moisture, at 1,330 feet per minute; and in a third, containing 15.9 per cent moisture, at only 1,150 feet per minute. At the lower extremity of the curves, considerable overlapping

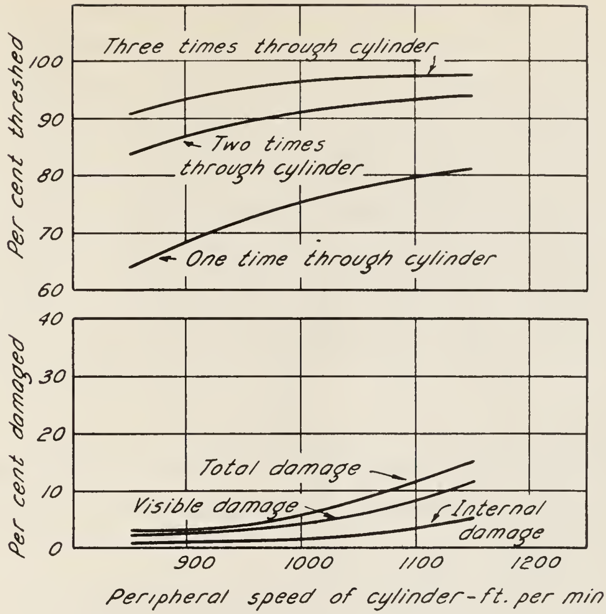

Fig. 11.—Threshing tests of Fordhook beans (moisture content 15.9 per cent). At a cylinder speed of 850 feet per minute the total damage was 3.0 per cent, and the amount threshed for three times through the cylinder was 91.5 per cent; while for a speed of 1,150 feet per minute the damage was 15.0 per cent and the thresh 97.5 per cent.

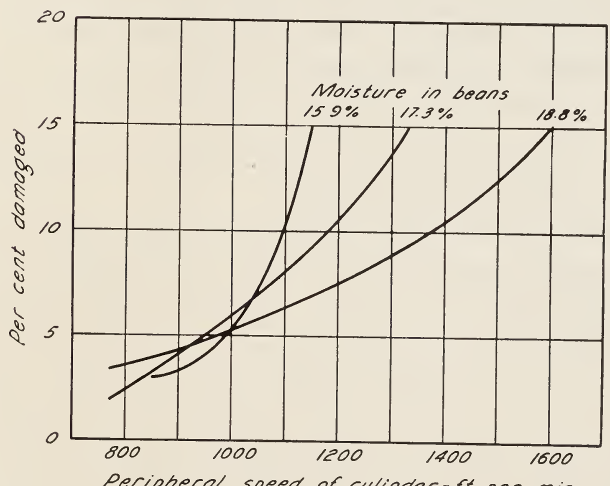

Fig. 12.—The cylinder speeds required to produce 15.0 per cent damage in Fordhook beans containing 15.9, 17.3, and 18.8 per cent moisture were 1,150, 1,330, and 1,600 feet per minute respectively.

occurs. The difference in damage for speeds of 1,000 feet per minute or less is not significant. Had the speeds in each case, regardless of moisture content, been kept at 1,000 feet per minute or less, the damage would have been approximately 5 per cent. Data presented in a later section of this bulletin indicate that beans of low moisture content are more susceptible to thresher damage than beans of higher moisture content.

In a special run with Fordhooks containing 17.3 per cent moisture, the cylinder speed was increased each time the straw was run through. At 770 feet per minute, the initial speed, 62.1 per cent of the beans were threshed, of which only 1.8 per cent were damaged. At 940 feet per minute, the speed used for the second run, 27.9 per cent were threshed, and 3.9 per cent were damaged. At 1,150 feet per minute, in the third run, the thresh was 6.7 per cent, of which 8.0 per cent were damaged. The remaining 3.3 per cent were shelled by hand. Total damage, recalculated on a prorated basis, amounted to 2.7 per cent of the crop. This example shows the necessity of operating at least the first cylinder at a minimum speed. Since over half the beans are threshed at this point, a large number will show little damage.

Cylinder speeds of 770, 940, and 1,150 feet per minute may be duplicated in a commercial machine having three cylinders, 21, 21, and 18 inches in diameter (tooth tip to tooth tip), respectively, from front to rear, by driving the respective cylinders at 140, 170, and 245 r.p.m. Under unfavorable conditions, a speed of 140 r.p.m. on the first cylinder is often too slow; but frequently beans should be threshed at that rate in order to produce high-quality seed. Naturally the capacity of the machine will be materially reduced in slowing down the cylinders. The cleaning-table speed must, however, be maintained even though the cylinders are slowed down. This may be accomplished by changing the gear or pulley ratio between the cylinder and the table eccentric drive, thus maintaining the speed of separation even though the beans pass through the cylinder more slowly.

The peripheral speed at which successive cylinders operate should be gradually increased from the front of the machine to the rear. If the speed of the first cylinder is kept to a minimum, a high percentage of damage-free seed will be threshed. Then, as the straw moves back through the machine, the remaining beans will be removed by cylinders operating at successively higher speeds. Although greater injury will result from the higher speed, the total damage in these cylinders will be smaller because most of the crop is threshed in the first one. The purpose of the third cylinder is to clean up the straw. Since, at this point, usually only 5 to 10 per cent of the beans remain, a higher speed with resultant higher damage to a few beans must be tolerated in order to remove most of the beans.

The third cylinder of several commercial machines studied was 18 inches in diameter. In most cases its rotational speed equalled or exceeded that of either the first or second cylinders; but because of its smaller diameter the speed on the periphery was slower. In a three-cylinder machine, for example, having cylinders 21, 21, and 18 inches in diameter, the rotational speed was 180, 216, and 216 r.p.m., respectively. When the rotational speed is converted to peripheral velocity at the tip of the cylinder teeth, the speed becomes 990, 1,185, and 1,015 feet per minute. In this case the last cylinder might well have been run at 1,500 feet per minute, if necessary for removal of the beans, without materially increasing the total damage, because the percentage threshed by this cylinder is small.

MISCELLANEOUS FACTORS AFFECTING QUALITY OF THRESHING

Rate of Feeding the Threshing Machine.—Trials were run with a commercial stationary thresher to determine approximately how the rate of feeding the machine affects the total damage. These tests were run in two lots of Fordhook beans containing 17.3 and 14.6 per cent moisture. The damage found in samples obtained from light, ordinary, and heavy feeding amounted to 6.0, 4.7, and 3.6 per cent, respectively, for beans containing 17.3 per cent moisture; 11.4, 8.6, and 7.4, respectively, for beans containing 14.6 per cent moisture. Though the differences are probably not significant, there seems to be a definite trend—a finding which agrees with the common opinion of threshermen that light or irregular feeding should be avoided. The portable pick-up machine is much more subject to irregular feeding than the stationary rig, because of the time that the machine runs empty while turning at the end of the row.

These tests on the rate of feeding, incidentally, illustrate again the effect of moisture content. The damage in beans containing 14.6 per cent moisture is practically twice that for beans containing 17.3 per cent.

Effect of Misalignment of Cylinder and Concave Teeth upon Quality of Threshing.—The clearance between cylinder and adjacent concave teeth must be sufficient to permit the seed being threshed to pass through. It amounts to approximately $\frac{5}{8}$ inch for different makes of bean threshers used in California.

Cylinder and concave teeth are often bent sidewise by rocks entering the cylinders with the beans or because of heavy threshing conditions. Consequently, the space between the cylinder tooth and the adjacent concave tooth on one side may be greater than the space on the other side. As a result, beans caught between the two teeth having the nar-

row clearance may be broken, while a whole pod may pass through the larger clearance untouched.

Occasionally the set collars on the cylinder shaft work loose, allowing the cylinder to slip sidewise, changing all of the clearances between cylinder and concave teeth. The result is end play. Sometimes the collars are reset against the cylinder shaft bearings, making this misalignment permanent. A few commercial machines were found with such misaligned cylinders. In one two-cylinder machine, threshing Henderson Bush beans, the cylinder had slipped sufficiently to reduce the clearance between cylinder and concave teeth to 1/4 inch on one side and to increase the clearance on the other side to 7/8 inch. A considerable number of the beans were not threshed, while the others showed a high percentage of visible damage but relatively little internal damage—the latter probably because of the comparatively low cylinder speed used (990 feet per minute).

Many threshermen believe that the most important single factor affecting quality of threshing is clearance between teeth (bent teeth). A few tests, therefore, were made in which as many as 40 per cent of the cylinder teeth were bent. The total damage done with the machine in this condition, illogical as it seems, did not differ significantly from that produced with the machine in proper adjustment. Although these tests were not numerous, the data apparently should have shown a trend if bent teeth were as important as previously assumed. Whether or not bent teeth contribute materially to the amount of damage, the operator should, of course, maintain uniform clearances between cylinder and concave teeth to insure thorough threshing. The factor of clearance between teeth is apparently less important than cylinder speed.

OTHER METHODS OF THRESHING

Disk Threshing.—One grower of Fordhooks was found threshing his beans with a single disk harrow set straight and drawn by a team of horses. A circular area in the field had been carefully leveled, and a layer of bean straw about 6 inches deep and 4 or 5 feet wide was spread in a large circle. This was driven over repeatedly, and the threshed beans were gradually worked to the center and the straw to the outside. The layer of material under the disk was kept several inches thick at all times to prevent damage to the beans. When the pile of threshed material in the center of the ring reached considerable size, threshing operations were transferred to an adjoining area while another crew cleaned and sacked the beans with a fanning mill. Upon analysis of the samples less than 1 per cent of visible damage was found, and the internal damage amounted to merely a trace. This method, although slow, gave

very good results with this operator and perhaps has some real merit, particularly for the small grower.

Roller Threshing.—Roller threshing of baby limas was once common and is still practiced to some extent. The beans are usually spread on large canvas sheets and are threshed with a large wooden roller drawn by horses. Although this method frequently gives good results, in some cases it produces considerable injury. In four lots of roller-threshed seed obtained from a seedsman, the damage ranged from 2.6 to 38.1 per cent. Since most of this presumably occurred during threshing, much care should be exercised even with the roller method.

EFFECT OF MOISTURE CONTENT OF BEANS ON THEIR SUSCEPTIBILITY TO INJURY CAUSED BY IMPACT

Data presented on preceding pages showed that beans of low moisture were damaged to a greater extent by a threshing machine operating at a given speed than were beans of high moisture content. Although moisture seems the most probable factor responsible, this point was not conclusively proved. It was necessary, therefore, to devise tests eliminating other possible factors and clearly showing the effect of moisture alone in this regard.

Experiments reported elsewhere[7] showed that injuries like those found in machine-threshed seed could be produced in the laboratory with beans that had been carefully hand-shelled. In this work the beans were placed on a table and snapped with a steel spring. When germinated, a large percentage produced damaged seedlings, whereas the hand-shelled seeds not subjected to this treatment showed no such seedlings.

Although this method gave satisfactory qualitative results, the speed of the spring could not be easily controlled and measured at the time of impact with the seed. Quantitative results were therefore out of the question, and other means of producing the impact had to be devised.

Since the intensity of a shock is determined by the speed of one object relative to another with which it collides, it matters little which one is moving. In the threshing machine the beans may be hit by a moving part, or they themselves may be moving and may be stopped by a stationary part of the machine. In either case they receive an impact. For these experiments it was convenient to make the bean the moving object and a steel block the stationary object. The beans were given their velocity by dropping them. During such a free fall they obey the law of falling bodies, which enables one to calculate their velocity at any given

[7] Borthwick, H. A. Thresher injury in baby lima beans. Jour. Agr. Research 44:503–510. 1932.

point. Air friction of course introduces an error; but this, in the range of distance used in these experiments, is negligible.

The equation covering the law of falling bodies is as follows:

$$V = \sqrt{2gh},$$

where,

V = velocity in feet per second.

h = height of fall in feet.

g = acceleration of gravity (32.2 feet per second per second). For determining the distance through which an object must fall to give it any desired velocity, this equation may be transformed to $h = \frac{V^2}{2g}$.

Calculations were made to determine the distances that beans must be dropped to give them velocities equal to those of the cylinder teeth when the various tests reported on preceding pages were carried out. These

TABLE 3

RELATION BETWEEN MOISTURE CONTENT OF WILBUR LIMA BEANS AND PERCENTAGE OF DAMAGE CAUSED BY IMPACTS OF DIFFERENT INTENSITY

Distance dropped, feet	Velocity attained, feet per minute	Moisture content: 5.8 per cent	9.6 per cent	14.1 per cent	15.9 per cent
		Total damage, per cent of sample			
2.55	770	40.7	18.2	2.7	1.0
3.81	940	52.9	28.7	.....	0.4
4.50	1,020	58.7	40.7	6.7	.....
7.61	1,330	86.0	57.9	.....	4.3
10.50	1,560	94.2	76.7	23.6	8.4

showed, for instance, that at the end of 2.55, 7.61, and 10.50-foot falls, velocities of 770, 1,330, and 1,560 feet per minute, respectively, were attained. A 21-inch cylinder, accordingly, rotating at 285 r.p.m. gives a bean no greater impact than does a free fall of 10.5 feet.

Experiments were therefore made to determine the amounts of injury produced in beans of known moisture content by dropping them various distances. The samples used were hand-shelled limas of the Wilbur variety containing 15.9 per cent moisture when shelled. One series of tests was made at this moisture content while other series were run at lower moisture contents obtained by slow drying. The various moisture contents used and the distance that the beans were dropped, together with their speeds at the time of impact, are indicated in table 3 and presented as curves in figure 13. Although the velocities of the beans at the time of impact were kept within the range of cylinder tooth velocities

used in threshing, direct comparisons between these and the threshing experiments are obviously impossible. In these dropping tests each bean receives one impact, and the impacts are very nearly equal. In machine tests some beans may possibly receive no impact at all, while others may receive several unequal ones. Comparisons, therefore, are to be made only among these dropping tests themselves and should not be extended to the machine.

Table 3 and figure 13 show that for any given intensity of impact the damage varies inversely with the moisture content. Five different

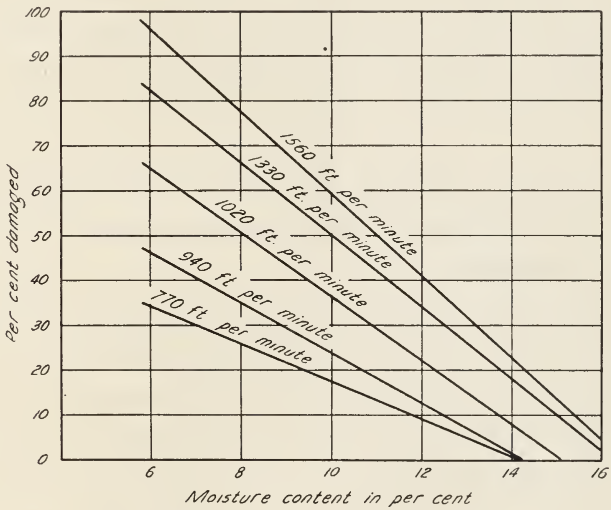

Fig. 13.—The relation between the moisture content of the beans and the percentage damaged. Velocities at the time of impact varied from 770 to 1,560 feet per minute.

impact intensities, as measured by the velocity of the bean at the moment of collision, were used; and this inverse relation between moisture content and damage held equally well in all cases. Similar experiments with the Fordhook, Hopi, and Henderson Bush varieties were carried out with similar results. Two lots of Fordhooks containing 11.1 and 15.9 per cent moisture, for instance, received 39.3 and 2.4 per cent total damage respectively from a fall of 2.5 feet. Three lots of Henderson Bush limas containing 10.4, 13.4, and 16.3 per cent moisture were injured 38.1, 12.2, and 1.7 per cent respectively by a fall of 10.5 feet.

The moisture content is thus established as fundamentally important in the threshing of seed beans. Although it cannot be controlled in the field, accurate knowledge of it is an important guide in determining how high a cylinder speed may be used with safety.

POSSIBLE SOURCES OF DAMAGE OTHER THAN THE THRESHING MACHINE

Growers and others have frequently maintained that the threshing machine is not the only source of damage to seed beans. Among several other places where they claim injury may occur, the chief is the seed-cleaning plant. The possible validity of this contention was not obvious until after the experiments reported in table 3. Since, for example, beans containing 9.6 per cent moisture may receive as much as 18 per cent damage in falling 2.5 feet, cleaning equipment obviously presents a definite hazard. The data of table 3 clearly showed the desirability of examining the more common types of equipment to determine whether or not they do subject the seed to impact of sufficient intensity to cause damage.

A survey, therefore, was made of the cleaning equipment of a number of California seed companies that handle lima bean seed in quantity. The object was to locate possible impacts and to determine their magnitude as nearly as possible.

Seed-cleaning plants are mainly of two types: one is several stories high; the other, one or two stories. In both, the beans are received in the bag and stored in the warehouse until cleaning time. In the case of the high warehouse, they are then elevated to the extreme top of the building in one operation and placed in temporary storage bins, whence gravity conveys them to the mills. There may be two or more mills, located on successive floors, and the beans go down from one to the other and finally to the hand-picking tables, where women remove split, cracked, or otherwise visibly defective seeds. The remaining beans then go to temporary storage bins below the tables, whence they are drawn off and sacked on the floor below. The bags are then piled in the warehouse until time for shipment.

In cleaning plants of the low type the beans are cleaned similarly except that all equipment is located on one or two floors. The seed, consequently, is elevated a short distance several times rather than a long distance once. These short elevations are accomplished by belt conveyors or, in some cases, by sacking the seed and elevating it in the bag.

The method of elevation varies in different plants. Sometimes freight elevators having a capacity of many bags per load are used, or chain elevators that carry the beans in bags. Still other plants use either large or small-type cup elevators. In one the buckets are large and move slowly; in the other they are small and move fast. The large buckets fill as they rise past a stream of falling beans and empty by tipping into a box at the top. The small buckets fill by dipping into a reservoir of beans

at the bottom; and, since they are moving fast, they empty by throwing the beans free of the elevator in going over the pulley at the top.

Some of these elevators may damage the seed, while others do not. There seems little opportunity for injury in those that handle sacks. The large-bucket bulk elevator should also be fairly safe. Although it is filled as the beans fall into it, they drop a very short distance; and since the speed of the bucket is not great, the combined speeds should not produce a very severe impact. When emptied out, the beans again receive a small drop; but this is also so short that little damage can result. The small-bucket elevator, however, is definitely open to suspicion. Its buckets travel so fast that they undoubtedly do some damage when they hit the beans in the reservoir at the bottom. In emptying, they throw their contents with considerable velocity, which is further increased by an amount determined by the fall. The speed of the beans at the time of impact is therefore rather high.

After leaving the elevator, the beans are delivered to temporary storage bins 15 or 20 feet deep. Instead of dropping directly to the bottom, they frequently roll down a series of slides from one side of the bin to the other. These slides are inclined at from 30° to 45° and in some cases are nearly 17 feet long. Upon reaching the bottom of each incline, the beans hit the wall before starting down the next one, receiving a rather severe impact that presents another possible point of damage.

Leaving these storage bins, the beans flow slowly through pipe conveyors to the machine below. Once these pipes are full, chances of injury are null. There is little opportunity for damage in the cleaner. Although the beans are shaken and slid about, they receive no free falls of any appreciable distance; and no other sources of impact were observed.

From the last cleaner the beans are taken through pipes to the hand-picking tables, where, of course, they receive no damage. As they leave these tables, however, they go down another inclined slide 3 to 6 feet long and hit the side of a small storage bin below the table. This impact may sometimes cause damage. No further impacts are received except those from filling the bags, which are presumably of little or no consequence.

Inasmuch as the seed-cleaning plants had finished the season's run before their possible importance in seed injury was understood, no experimental work could be done in them. Certain features of the warehouse that seemed to present the most probable sources of damage were, however, duplicated in the laboratory. On slides constructed, for example, at a 45° angle, hand-shelled baby lima beans were allowed to roll various distances before hitting a board at the bottom comparable to the side of the bin. Beans of 10.6 per cent moisture content, rolled down

this slide, showed total damages of 4.5, 8.6, and 15.3 per cent, respectively, for slide distances of 6.4, 10.4, and 15.0 feet. Tests of the same kind with Fordhook beans gave similar results.

These experiments show very clearly that much damage may be produced in beans in the warehouse, where they may go down such slides more than once. In one laboratory test the same lot was sent down a 45° slide 15 feet long three times in succession. The total damage was 42.8 per cent, representing an average accumulation of 14.2 per cent injury for each time over the slide. This figure agrees very well with the 15.3 per cent damage obtained by running a similar lot over the slide a single time. Since a slide of less than 7 feet caused 4.5 per cent damage, beans might receive some injury even after leaving the picking table.

In a comparison made, hand-shelled beans from the same source were dropped upon a steel block, upon a pine board, and into a bucket of beans. In the last case the beans already in the bucket were differentiated by staining. All lots fell 10.5 feet. Total damage resulting was 63 per cent for dropping upon steel, 21 per cent for dropping upon a pine board, and 9 per cent for dropping into beans. Evidently, therefore, beans are damaged significantly even by falling into other beans.

Damage was also found in baby lima beans run down a 30° slide. The amount was less, however, than with a steeper slide. For example, beans received about 16 per cent damage from a slide of 15 feet at a 45° angle and only 6 per cent from a slide of 21 feet at a 30° angle, yet each slide lowered the beans the same distance.

The laboratory experiments in imitation of warehouse conditions were performed with seed containing approximately 10 per cent moisture. Had the moisture content been higher, the damage would have been less. Under some moisture conditions the beans would probably have survived any of these treatments without serious damage; but 10 per cent is not an unusually low moisture content, particularly for baby limas grown in the interior valleys. If beans are handled with as little moisture as this, evidently extreme care must be taken.

Although many of the drops that beans receive in the warehouse are rather short and probably do little damage, some harm is nevertheless done; and since these small drops occur repeatedly, the total injury may be considerable.

A further point brought out by experiments involving the dropping of beans was that the damage resulting from impacts of low intensity is mostly internal. As the impacts become more severe, visible damage makes up a greater part of the total. Since many of the impacts in the warehouse are not severe, a large part of the harm done is probably internal.

It has also been found that internal injury makes up a greater portion of the total injury in beans of high moisture than in beans of low moisture. As the moisture increases, the amount of visible injury resulting from cleaning processes will decrease very quickly; and such damage as does accumulate will be largely overlooked because of its internal character.

The planter has also been suggested as a possible source of damage. Although it did not appear important in the case of seed beans, comparative tests were made with planters of both the plate and pick-up types. After samples of hand-shelled beans had been run through, the seeds were germinated. Although an occasional bean was cracked, no significant injury was found. If the planter is properly adjusted and operated it seems thus definitely eliminated as an important source of damage to seed beans.

SUMMARY

Many types of beans are damaged for seed purposes at the time of threshing, or later, during the milling and handling operation. The lima varieties appear to be the most difficult to thresh without injury. Damage may be either visible or internal. The latter is more serious because it cannot be detected until the seeds are germinated. Beans so injured produce mutilated seedlings in which parts are either missing or broken.

Peripheral velocity is a more satisfactory basis than speed of rotation for comparing the effects of cylinders having different diameters and operating at different speeds.

Cylinder speed and percentage of damage are directly related; the greater the speed, the greater the damage. Total damage to a lot of baby lima beans, containing 9.1 per cent moisture, varied from 7.6 to 52.5 per cent at threshing speeds of 770 to 1,560 feet per minute.

A lot of baby lima beans containing 16.4 per cent moisture showed 1.0 and 21.0 per cent damage, respectively, at cylinder speeds of 770 and 1,785 feet per minute.

High moisture content in the beans permits higher cylinder speeds to be used without an increase in the total damage.

The cylinder speeds required to produce 15.0 per cent total damage in Fordhook beans containing 15.9, 17.3, and 18.8 per cent moisture were 1,150, 1,330, and 1,600 feet per minute, respectively.

A thresher having only one cylinder is not suitable for seed beans, because the speed necessary for thoroughness is too high for the production of damage-free seed.

A low speed on the first cylinder of a two or three-cylinder machine usually insures the threshing of a high percentage of the crop with a

minimum of damage. If speed on successive cylinders is increased, the threshing can be completed without damaging a high percentage of the seed.

More damage apparently occurs during light feeding of the threshing machine than during ordinary or heavy feeding. For example, the total damage to Fordhook beans containing 14.6 per cent moisture amounted to 11.4, 8.6, and 7.4 per cent, respectively, for light, ordinary, and heavy feeding.

Fordhook beans carefully threshed with the ordinary disk harrow, set straight, showed only 1.2 per cent total damage.

The total damage to four lots of baby lima beans, threshed by rolling, varied from 2.6 to 38.1 per cent.

According to laboratory tests in which beans of various moisture contents were subjected to impacts of equal intensity by dropping them known distances, beans of high moisture receive less damage than beans of low moisture. The results agree with those obtained from threshing tests in the field.

Moisture content is of fundamental importance in the threshing of seed beans. Although uncontrollable, it is nevertheless an important guide in determining how high a cylinder speed may be used with safety.

The fast-moving cup-type elevators and the steep slides found in bean warehouses are the most likely points where damage to seed beans during handling may occur. Beans of 10.6 per cent moisture content, rolled down a 45° slide, showed total damage of approximately 4.5, 8.6, and 15.3 per cent respectively for slide distances of 6.4, 10.5, and 15.0 feet. Comparative tests showed that neither the plate nor the pick-up type of planter produces any appreciable amount of damage.

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